Experimental and LSP modeling study of pre-pulse effects on the laser-plasma interaction by using a 527 nm laser pulse

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Motivation

• Is a high contrast, $2\omega$ (527 nm) pulse better for fast-ignition?
• High contrast pulse vs. one with pre-pulse
• Not possible to directly measure what happens in the LPI
• Fielded wide array of diagnostics for indirect measurements
• Can we simultaneously reproduce ALL these results within a single simulation to better constrain the pre-pulse effects?
• If so, then more confidently read out quantities of interest using well benchmarked simulations
We create a high contrast pulse with optional pre-pulse to study relationships between LPI and hot-electron source and transport.

**LLNL’s Jupiter Laser Facility**

- **2ω Titan Short Pulse**

1. Specular reflectivity/absorption
2. Time resolved specular pulse
3. Electron transport

**λ₀ = 527 nm (2ω)**

- **τ_{FWHM} = 600 fs**
- **E_{total} = 50 J**
- **x_{FWHM} = 8 µm focal spot**
- **I_{peak} = 5 x 10^{19} W/cm² (a₀=3.2, E_p=1.2 MeV)**

(Optional 3 mJ / 3 ns pre-pulse)
Specular reflectivity ~2x higher for no pre-pulse

- No Pre-pulse
- 3 mJ Pre-pulse

- Speckled Features 25-40% Reflectivity
- Smoother beam profile 10-15% Reflectivity
Large red-shift (~2.5%) on the rising edge of specular beam with injected pre-pulse.

Early red shift previously observed with λ₀ = 1 µm interaction attributed to Doppler shift from electron density profile steepening.

* Ping et al, submitted to PRL
Electron beam divergence from K_α images

Spherically bent Bragg Crystal
[8048 ± 2.6 eV]
Increased $K_\alpha$ divergence (~60%) with injected pre-pulse.

- No pre-pulse
- 3 mJ pre-pulse
- 25° Full Angle
- 40° Full Angle
Full scale LPI 2D3V fully collisional kinetic PIC simulations in LSP* to gain further insight about pre-plasma effects

LASER:
- Polarized in the plane
- $\lambda_0 = 527 \text{ nm} (2\omega)$
- $T_{\text{FWHM}} = 700 \text{ fs}$
- $x_{\text{FWHM}} = 8 \mu\text{m}$ focal spot
- $I_{\text{peak}} = 4.6 \times 10^{19} \text{ W/cm}^2$

SIMULATED DIAGNOSTICS:
- 1. Unabsorbed light fraction
- 2. $n_e$ profile steepening
- 3. Cu $K_\alpha$ divergence

Pre-plasma environments chosen using the reflectivity data

Simulated motion of critical surface consistent with rising edge red shift seen in specular pulse

Experimental Results
No pre-pulse: $\Delta \lambda / \lambda_0 < 0.5$
3 mJ pre-pulse: $\Delta \lambda / \lambda_0 \approx +2.5$

Simulation Results
$L = 1.3 \ \mu m$: $\Delta \lambda / \lambda_0 \approx +1.4$
$L = 3 \ \mu m$: $\Delta \lambda / \lambda_0 \approx +5$
Increased simulated $K_α$ divergence (~40%) with increased pre-plasma.

Experimental Results
- No pre-pulse: 25°
- 3 mJ pre-pulse: 40°

Simulation Results
- $L = 1.3 \, \mu m$: 35°
- $L = 3 \, \mu m$: 50°
Very good agreement between experimental and simulation trends with increasing pre-plasma.

- Full scale target simulation with self-consistent LPI and electron transport.
- With increasing pre-plasma, in both experiment and our modeling we observe:
  - Decreased reflectivity
  - Increased critical density movement
  - Hotter source electron energy spectrum
  - Increased Cu $K_\alpha$ divergence
- Pre-plasma only unknown in simulation.

For further insight into pre-plasma effects on experimental observables, we complete the restraint on the pre-plasma environment by simultaneous diagnostic matching.
Kα imager data can be misleading

Approx. half the collection efficiency of deeper fluors

Short pulse (100 fs) simulations used to determine pre-plasma environment by matching specular data.

- **No pre-pulse:**
  - Experimental reflectivity ranged from 20-30%

- **3 mJ pre-pulse:**
  - Experimental reflectivity ranged from 10-15%

**Still determining whether or not this result is physical.**

**Long pulse results:**
- $L = 1.3\mu m$, 30% reflectivity
- $L = 3\mu m$, 24% reflectivity
Increased Cu K$_{\alpha}$ FWHM divergence (~50%) with injected pre-pulse

No Pre-Pulse

3 mJ Pre-Pulse

***Data normalized to peak value***
Escaped electron energy spectrum is ~30% hotter with injected pre-pulse

As measured in vacuum, related to LPI born electrons*

$kT_{ave} \approx 1.5\pm0.3\ MeV$

$kT_{ave} \approx 2.0\pm0.3\ MeV$

* Link et al, Phys. Plasmas 18, 053107 (2011)
Time integrated simulated SOURCE electron energy spectrum ~20-40% hotter with increased pre-plasma pre-plasma.

\[ kT = 5.6 \text{ MeV} \]
\[ kT = 7.8 \text{ MeV} \]

\[ kT = 2.1 \text{ MeV} \]
\[ kT = 2.5 \text{ MeV} \]

\[ kT = 5.6 \text{ MeV} \]
\[ kT = 7.8 \text{ MeV} \]

Complicated energy downshifting, now understood*

\[ L = 1.3 \mu m \]
\[ L = 3 \mu m \]

Same experimental trend observed, however consistently hotter than what was measured

* Link et al, Phys. Plasmas 18, 053107 (2011)